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THREE-DIMENSIONAL INPUT FOR COMPUTER GRAPHICS

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34

ABSTRACT

THREE-DIMENSIONAL INPUT FOR COMPUTER GRAPHICS

Jay A Schadel and Stephen L. Macdonald

This paper states the need for three-dimensional input for architectural work using computer graphics. The paper consists of two sections. The first section deals with laser scanning; <u>x</u>, <u>y</u>, being a mechanical scan, and <u>z</u> being a modulated laser source timing the reflected laser beam. The second section explains the use of photogrammetry for <u>x</u>, <u>y</u>, <u>z</u> information. (Photogrammetry is the science of measuring using photographs.) Examples are given comparing old methods of ground survey with photogrammetry.

THREE-DIMENSIONAL INPUT FOR COMPUTER GRAPHICS

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At one time most architectural design decisions were made at the construction site. As buildings and cities became complex, more and more of these decisions were made in offices away from the site with a growing dependence on survey data, photographs, and other related information. With the exception of photogrammetry, speed of the taking of data via surveying has progressed little. Accuracy has improved with the use of tellurometers and other sophisticated equipment. Also, discrepancies between data obtained by different survey crews have slowed down the process further still. The need now exists for fast, accurate ways of determining topographic information, as well as site landscaping, services, and facilities. The following is a tentative evaluation of two techniques in the state of the art of three-dimensional input for computer graphics.

For example of the type of information needed by the architect, let us take a brief survey of a typical metropolitan area. The size, shape, and relative position of buildings (facade details and overall measurements), bridges, utilities above and below ground (water towers, water, gas, electric, telephone, T.V., sewer), streets, street lighting, traffic signals, benches, curbs, parks and other objects within the cityscape must be known and recorded. The list becomes enormous when semi-movable objects are considered--cars, trucks, etc. This example does

not include information from the s[illegible] and related facilities as airports, industrial areas, and other supporting facilities for the city.

From the city we turn toward problems more micro in character, the interiors of existing buildings, and how this three-dimensional information relates to the exterior environment.

The need for a three-dimensional graphic input system that is reliable, accurate and fast is shown by the disputes that have arisen because of property line court cases.

Architects' requirements for a three-dimensional graphic input system are listed below:

(1) Reliability - Must be substantiated by testing system against conventional surveying systems.

(2) Accuracy - 1 part in 25,000 or better (± 1/10 of a foot in 200 feet)

(3) Speed - Three-dimensional data taken should be available to the architect within one 8-hour period.

(4) Automation - To reduce errors the system should be as automatic as possible.

(5) Timing - Must have all three-dimensional information about topography and architectural objects available at the same time.

Using these requirements as a guideline, the writers investigated the state of the art of scanning that could be used for obtaining three-dimensional information about architecture. Laser scanning systems and the older field of photogrammetry are compared as systems applied to architecture. Although the new field of laser scanning showed promise for the future,[5]

[5]The first range finding equipment was developed in Glasgow, Scotland by Barr and Stroud Ltd. in 1964. Accuracy was ± 10 meters in 10,000 meters.

the only system that is operational is a laser profiling system[11] which gives only one dimension instead of the three required. (A description of this system and how it might be changed to a three-dimensional system will follow.)

The well established art of photogrammetry was also investigated as to its three-dimensional architectural use. Photogrammetry is defined as "the science or art of obtaining reliable measurements by means of photography."[1] This definition might well be amplified to include "interpretation of photographs" as a function of nearly equal importance, for the ability to recognize and identify a photographic image is often as important as the ability to derive its size, shape, and relative position from the photographs.[6]

LASER SCANNING

In one of the early exploratory efforts in this field, Norden Division of United Aircraft operated a working model scanning laser radar as part of a company sponsored program to develop a short-range (2 mile) airborne obstacle detector. This detector would deliver range and x, y position of an object relative to the position of the receiver.

[11]Aero Service Corp. has flight tested a new photo mapping system which uses a gas laser altimeter developed by Spectra-Physics. By utilizing a low-powered, continuous wave, gas laser altimeter with a narrow beam, accuracies of ± 6 inches can be achieved. It has the additional value of being used as a highly accurate profiler as well as an integral part of an airborne mapping system. However, this profiler is used only in conjunction with conventional photogrammetry as a check system.

Using a Spectra-Physics helium-neon laser, which generates 5 mw. of continuous wave output power, Norden engineers have successfully identified [illegible] cables at a distance of 400 ft. near its plant in Norwalk, Connecticut. At [illegible] ft. the sensor could sense the three-dimensional relief of automobile license plate numbers and present the image on a cathode ray tube for interpretation.

While this is an extremely low-power device with a maximum range of only 500 to [illegible] ft., it offers some idea of the range and results that a laser beam scanned in two dimensions can supply. The working model laser radar provided reasonable returns even under conditions of light haze.

The company expects to be able to obtain 10-deg. scan in both azimuth and elevation using the ultrasonic cell concept, or as much as 20 deg. in azimuth and 10 deg. in elevation using a combination ultrasonic cell and mechanical scanner. A completely mechanical scanner should yield ± 10 deg. in both azimuth and elevation. This is still a narrow scan as compared to the wide angle coverage (35°-40°) of a photographic system.

Norden's working model sensor consists of the gas laser, the two scanners, an astronomical telescope, a photomultiplier receiver, and a synchronized cathode ray tube display. The receiver includes a collecting lens, an adjustible iris, spectral filter, the photomultiplier, and wideband video amplifier. The cathode ray tube beam is driven synchronously with the laser scan to generate the scanned information on a cathode ray tube display.

Interestingly, the concept of two-dimensionally scanned forward looking laser sensor is analogous to an extension of the laser line scanning camera system in which the beam is scanned electromechanically in one direction and by the forward motion of the aircraft in the other.

While the Norden development centered around a continuous wave laser; the company, like others becoming active in the area, is investigating the use of pulsed lasers, particularly neodymium-doped yttrium aluminum garnet devices. In a pulsed system, the receiver can be synchronized with the transmitter to eliminate deleterious effects of back-scatter, a serious problem for a continuous wave system.

Other obstacle detector component concepts, including a linear array receiver and a scanning aperture photomultiplier are being evaluated at Norden.

The linear array is a line of photodiode detectors of which the currents can be resolved to give an image of an object on a cathode ray tube display of view.

The Q-switched ruby laser beam is scanned in only one direction at a time by a mechanically-driven optical reflector. A range versus azimuth or range versus elevation, cathode ray tube type of presentation is generated.

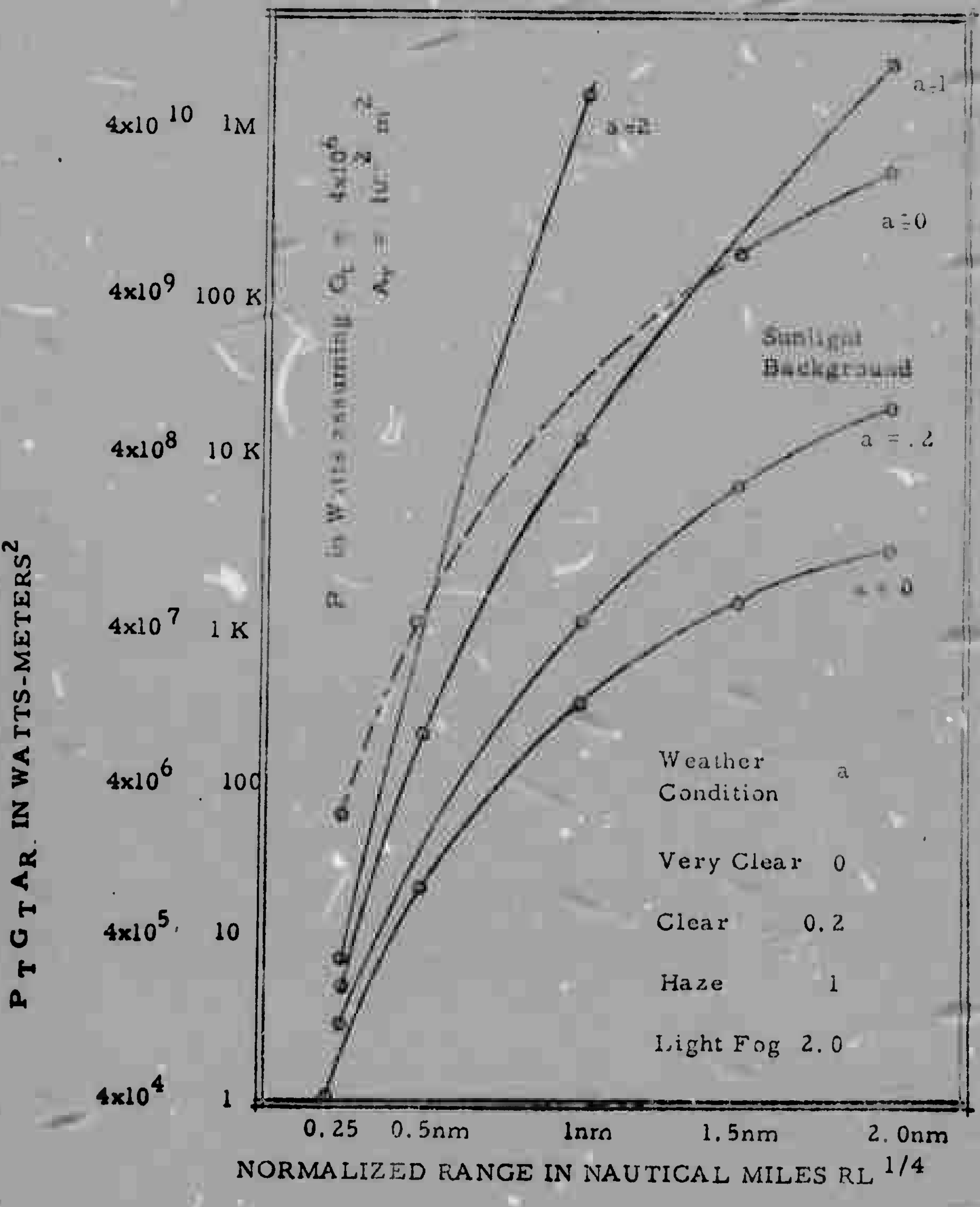
The laser is scanned over a 15-deg. scan angle, although this could be enlarged to 30-deg. if a larger viewing port were available. It operates at a 100-pulse-per-sec. rate.

Raytheon expects that its liquid-cooled neodymium-doped laser rangefinder could be adapted for obstacle avoidance applications or for obtaining x, y, z information of existing objects. The device ranges successfully out to 5 1/2 kilometers with an accuracy of 1:50,000.

The graph on page seven shows what Norden calculates as the effects of weather and systems losses on the maximum range of a pulsed neodymium laser radar. The attentuation coefficients correspond to very clear, clear, hazy, and light fog weather conditions. The graph does not, however, account for improvement in the sensitivity of signal detection devices.

One of the two ordinates is a product of transmitter power, transmitter gain and receiver aperture, factors that may be traded against one another in system design. The other is the transmitter power required, assuming typical values of transmitter gain and receiver area for a compact laser radar. The broken curve corresponds to the case of a very clear weather with sunlight background.

Norden has been running extensive simulation studies to determine the effects on laser radar of a host of parameters, including maximum target view, transmitter beamwidth, transmitter power, weather attenuation, target distance change per computation and number of beamwidth samples taken.

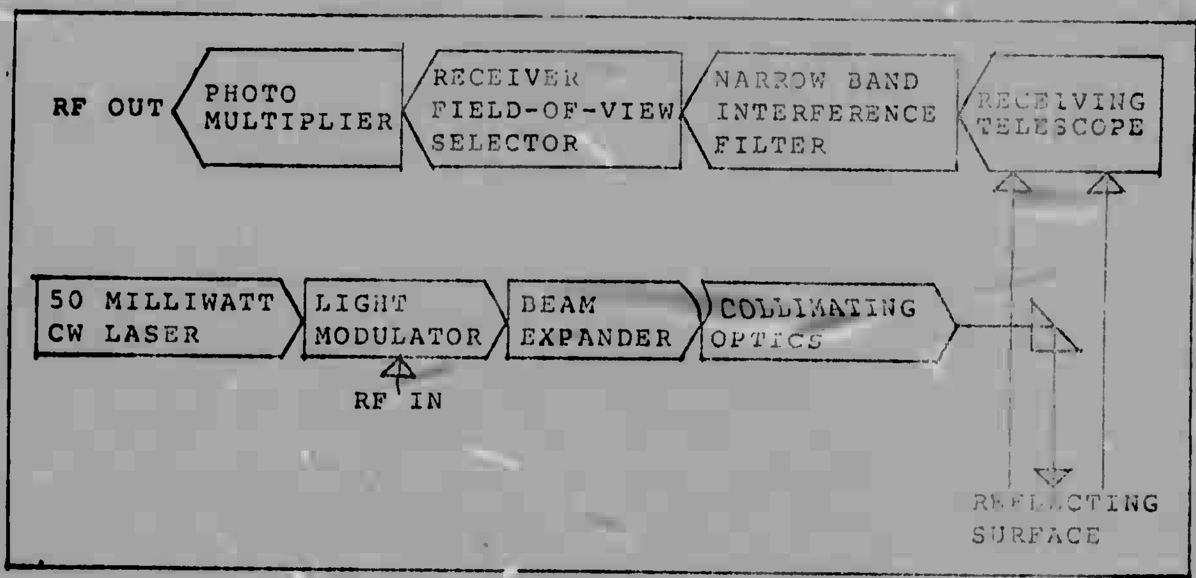


LASER RADAR RANGE, plotted for varying weather conditions, falls off sharply during haze and light fog. Left ordinate is a product of peak transmitter gain and receiving aperture area, parameters which can be traded in laser radar design. The second ordinate is peak transmitter power.

Graph from AVIATION WEEK

LASER PROFILING SYSTEM

In June, 1967 John Cotsworth of Spectra-Physics at Mountain View, California described fundamentals of geodilite system (laser rangefinder). Below is a schematic of this system.



Transmitting and receiving optics of laser altimeter are coaxial so that receiving telescope views terrain area scanned by the transmitted light beams. The optical path is indicated by the block diagram of the optical portion of the altimeter.

The device uses a helium gas laser beam that permits a target to be selected from a confusing background without spurious returns and accurately determine the range to 1:50,000.

Laser light reflected from the object is picked up by a 6" diameter Schmit telescope which is coaxial with the transmitting optics, passed through a filter to eliminate spurious light, then a field of view selector assembly and impinges on the sensitive elements of a photomultiplier.

The RF outputs are filtered into their respective channels. These signal returns are compared with the transmitted signal contained in a reference channel to determine a phase difference, which is a measure of the round trip propagation time. This system is used as a profiling device in conjunction with photogrammetry. Output may be analog or digital.

Mr. Cotsworth indicated that it would be possible to adapt the geodilite for three-dimensional information retrieval, but extensive research and development would be required to fulfill the requirements needed by the architect listed on page two.

HI-FIX MODIFIED DECCA SYSTEM

The basic system uses three slave and one master radio receiver transmitter. The precise location of the three slave stations relative to one another is known. Based on this knowledge the $\underline{x}$, $\underline{y}$, $\underline{z}$ location may be calculated by knowing the altitude and azimuth of the received signal from the master station compared with the information from the other slave stations. In all cases the master transmitter must be at the position at which you wish to make the measurement. This means that a person would have to be at the master transmitter location. Thus, in effect, a surveying team would have to scale buildings or be at the precise location that the information is to be obtained. This system is used for long-range navigation, 250 miles with accuracies $\pm$ 125 feet. The Hi-Fix Modified Decca System cannot be used for a scanning device.

Table 1

Lasers with the Greatest Possible Application for Terrain Mapping or Profiling

TYPE	OUTSTANDING CHARACTERISTIC	ORDER OF MAGNITUDE OR EFFICIENCY ACHIEVED
Pulsed Ruby	Energy/Pulse Narrow beam angle	1500 Joules .001 Radian
Continuous Wave Neon Helium	6428 Angstrom *(Red Beam)*	Diffraction Limited Single Mode
Gallium Arsenide Injection	Efficiency and Direct Modulation	About 50% Efficiency 20 Degrees Kelvin

Problems Requiring a Solution:

Systems and Quality Assurance Engineering - One major problem confronting equipment manufacturers is quality control of the parts that are produced by subcontractors.

It is the opinion of several manufacturers of laser scanning equipment that the engineering problems would require further research.

PHOTOGRAMMETRY

Categories of Photogrammetry

Photogrammetry is frequently divided into specialties or categories, according to the position of the camera relative to the object being taken. For instance, the type of photogrammetry used when the photographs are taken from points on the ground surface is called ground photogrammetry or terrestrial photogrammetry.[1] Photographs taken on the ground with the optical axis of the camera horizontal are called horizontal photographs. Aerial photogrammetry connotes the use of photographs which have been taken from any airborne vehicle, and these may be either vertical aerial photographs or oblique aerial photographs.[1] Stereophotogrammetry means that overlapping pairs of photographs are observed and measured, or interpreted, in a stereoscopic viewing device, which gives a three-dimensional view and creates the illusion that the observer is viewing a relief model of the terrain or object.[1] In analytical photogrammetry, the geometric problems are solved by mathematical computation, using measurements made on the photographs as input data. In most cases the computations are accomplished by using a computer coupled with a stereoscopic viewing device.[2]

The problems involved with architectural photogrammetry would not be as complicated if only one type of photogrammetry were involved, but this is not the case. Terrestrial, aerial, and horizontal photogrammetry must be used if all of the

visual information is to be realized for the architect's use in the planning of the urban and suburban scene.

Major Problems of Aerial Photogrammetry

The difficulties which beset photogrammetrists in their efforts to obtain precise measurements and compile accurate maps or other data from aerial photographs arise mainly from the two general sources stated below:[1]

A. Conditions for obtaining and preserving the original negatives are seldom ideal.

B. Transfer of the information contained in the original negatives to the map compilation can seldom be carried out with complete accuracy.

In order to gain an appreciation of the variety of difficulties which can arise from these sources, the requirements for one of the most exacting uses of photogrammetry should be considered, namely, the preparation of an accurate topographic map.

A. Conditions of Photographing and Processing

To illustrate why it is seldom possible to take the original photographs under ideal conditions, several requirements are listed below, all of which would have to be fulfilled in order to obtain perfect original photographs and to prepare the map or plot in the most economical manner.

1. Each exposure should be made exactly at the ideal position determined in advance.

2. The optical axis of the lens should be exactly normal to the object at the instant of exposure. (Most architectural photogrammetry does not lend itself to this condition because of cramped conditions in cities. Some of the oblique angle problems have been solved at the Ohio Experimental Station by Perry E. Borchers.6)
3. The camera should be oriented in azimuth at the instant of exposure, precisely as planned in advance.
4. There should be no forward movement of the aircraft relative to the ground during the time of exposure. (At 300 ft. per sec. a plane will move 1 ft. in 1/300 sec. In terrestrial photogrammetry this does not apply.)
5. The camera lens should be free of distortion and otherwise optically perfect.
6. The camera should have stable and known metrical characteristics, and should be in perfect adjustment.
7. The emulsion-bearing surface of the photographic film or plate should be perfectly flat and perfectly oriented with respect to the lens at the instant of exposure.
8. The emulsion should be of uniform thickness and should give infinite resolution.
9. Atmospheric conditions while taking the photographs should be perfect.

B. Transferring Information from the Photographs

The second general source of difficulties connected with the preparation of accurate maps from aerial photographs stems from the several procedures involved in making measurements on the original photographs, or negatives, and in transferring quantitative information from the photographs to the map-compilation sheet. Some of the operations which can and do frequently entail difficulties at this stage of the photogrammetric process are:

1. Developing the original negative films or plates.
2. Making positive prints from the negative films or plates.
3. Operating the photogrammetric plotting instruments. (Which correct for parallax, tilt, etc.)

The processing or developing of the original negative films or plates, particularly films, is an extremely critical operation, and requires meticulous care, thorough workmanship, proper equipment, and professional skill. The original efforts are wasted if the films are later carelessly processed and improperly developed. Not only must the chemical treatments be applied properly to bring out the maximum in image quality and to prevent "creeping of emulsion," but it is equally important that the film base be handled carefully and properly in order to reduce to a minimum the expansion, shrinkage, stretching, warping, curling, and even tearing of this material.[1]

In most aerial survey procedures, the original negative films or plates are not used in the actual compilation work. Instead, for convenience, positive copies of one type or another are used. These positives may range from ordinary prints on photographic papers to the transparent positives on glass plates required in the precise plotting instruments. These glass plates are variously called diapositive plates, lantern slides, or transparencies. They are usually made by exposure through a lens in a ratioing printer or reducing camera, but in some cases, the positive plates are made by being exposed while in direct contact with the negatives. The precautions and requirements which were noted as necessary for the best results in developing the original negative films are equally necessary in making the positive prints.

Further difficulty and loss of accuracy are possible, and probable, in the operation of the various plotting instruments used for transferring map details from the photographs to the map sheet. These instruments are exceptionally efficient optical and mechanical devices, but are necessarily complicated and delicately balanced, and hence can be and frequently are the source of many troubles and problems. Although the instruments produce excellent results, it is still true that much of the effectiveness of the compilation work is dependent upon the exercise of good technical judgment by the operator of the instrument, and upon the acuity of his stereoscopic vision.

There are, in addition, various extraneous problems and difficulties which occur during the compilation stage of a survey project. An example of a major problem of this sort is the not uncommon situation in which there is a deficiency of suitable ground survey control. Deficiency in this case may mean insufficient quality, poor distribution, low accuracy or difficulty of proper identification. Suitable ground-survey control is required for all photogrammetric survey systems. The problem of acquiring this control is an important consideration affecting the possible volume of information output. This is an economic as well as a technical problem because, in some instances, the cost of control has rendered the use of certain photogrammetric methods prohibitive. The reduction to a minimum of the required amount of ground control is still a widely-pursued object of photogrammetric research.

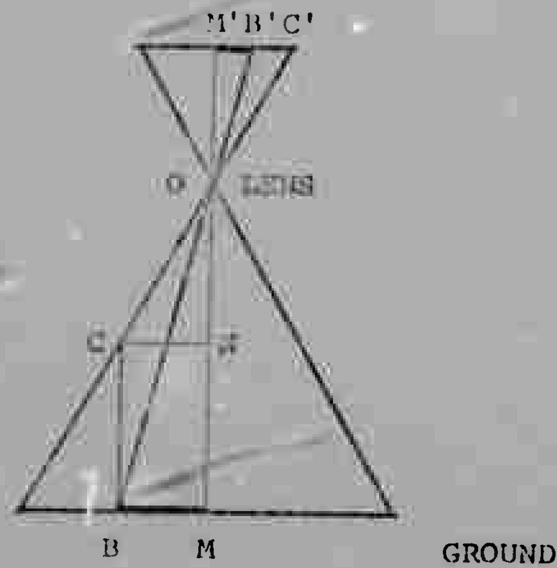
At this point it is difficult to complete an analysis of cost, but referring to an article in Industrial Photography[4] which states: "In recent years there has been an increased demand for accurate inventories of material stock piles which can be done in a limited amount of time. Hugh construction projects and the Federal Highway Program have created situations in which the old methods of ground survey have become inadequate due to the time and personnel required and the lack of accuracy. Photogrammetry can do the job at a 25% reduction in cost."

C. Character of the Earth's Surface

The character of the surface of the earth itself causes difficulties for the photogrammetrist. If it were possible to take a truly vertical photograph of flat and level terrain, and if the effects of atmospheric refraction and lens distortion were compensated, the perspective view shown on the aerial photograph would be identically the same as an orthographic projection. It would thus be a true source map and the photogrammetrist's problems would be greatly reduced. There has been, in fact, a notable and successful effort to produce modified photographs which are nearly orthographic; but these orthophotographs are still limited in availability and do not represent the conventional situation in photogrammetry. However, because of the geometric and planar character of architecture, it is easier to produce maps of architectural subjects than uneven terrain. The operator can easily pick out points to be marked and measured on architectural subjects than the random search techniques used on terrain.

A factor of major importance, however, is relief of the terrain. To illustrate how the difference in elevation displaces the position of a photographic image, consider an aerial camera with lens at point O, figure 1-16, and the tower BC rising above flat ground surface BM. In nature, MB=NC, but on the negative these distances are recorded as M'B' and M'C;, respectively; the distance M'C' being inconsistent in scale with other distances on the negative because

of the elevation of C above the surrounding terrain. It should be noted, however, that the displacement of photographic images because of relief is the basis for determining elevations and contours from the photographs.[1]



Solution for the Problems

The foregoing problems are some of the major ones which confront the photogrammetrist in his efforts to carry out accurate surveys from aerial photographs. The descriptions of these basic problems are not intended to have a discouraging effect nor to paint a pessimistic picture of the future as it applies to architectural photogrammetry. Actually, the picture appears quite optimistic, as remarkable results are already being achieved, in spite of the handicaps of imperfect source materials and other difficulties which have been described. These results could be better in many cases,

however, and hopefully could be attained with less effort and at lower costs. Cost of a photogrammetric project is related directly to the degree of accuracy desired. Under ideal conditions accuracies of 1/50,000 are possible, under normal conditions 1/25,000, under adverse conditions 1/1,200; which means that at 300 feet from the object being photographed 1/8" accuracy can be obtained using 1/25,000 as the condition most often encountered.[6]

Future Outlook for Photogrammetry

Photogrammetry is a comparatively modern science and many of its problems are still to be solved.

Several developments that may be reasonably anticipated in the near future include:

1. Development of methods to reduce the amount and/or cost of ground control needed for surveys, especially by the use of electronic instruments in the field and the further development of analytical aerotriangulation in the office.[2]
2. Further development of either or both stabilizing mounts for cameras, or verticality indicators.[1]
3. Further improvements in quality of photographic imagery.
4. Advance in color photography for photogrammetric use.
5. Greater utilization of new sensors such as radar, laser, and infra-red to supplement or replace conventional optical photography.

6. Continued [illegible] ric instr[illegible].

7. Inc[illegible] particularly in [illegible] of auto- matic [illegible].

In spite of the [illegible], photogrammetry allows the archit[illegible] to choose and recog[illegible] about the existing arch[illegible], colors (color photogr[illegible] and land- scape features. [illegible] and shadow are indicated on the [illegible]. Infra-red photogrammetry can be used to locate [illegible] or cold for planning the outdoor environ[illegible] could be plotted along with the other [illegible] to the archi- tect. From [illegible] architect would have at his disposal, a rich [illegible] of design criteria from which to choose.

In conclusion, the [illegible] information about architecture via [illegible] profiling and photogrammetry pose[illegible] research and deve- lopment groups of both [illegible].

Laser profiling [illegible] of information to an amount that a computer [illegible], a serious draw- back is that if more informat[illegible] required, an additional

trip must be made. If a TV [illegible] were used in conjunction with the laser profiler, the [illegible] could view the existing condition and relay back to the [illegible] exactly the type and location of information [illegible] required. Then a more accurate data base could be [illegible] by the architect.

Photogrammetry is an ideal system for capturing complex, irregular, and elusive [illegible] for detailed examination and measurement. In an instant of time, vast amounts of information are available for digestion by the architect. Also new techniques such as remote sensing devices where land use patterns become more prominent will further augment the available information.

While it is not likely that more variety of information can be obtained from survey devices other than photogrammetry, it is possible that more accuracy and speed might be developed through such instruments as laser scanners. The line of sight measure is instantaneous, accurate and with optional digital read-out. This is obviously simpler than photogrammetric processes involving more than one hundred thousand dollars worth of equipment, and five or six processes, including the final judgment of an operator. However, to date there is nothing which seriously competes with photogrammetric methods for high resolution and wealth of information.

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